XV. Cubic surface of the fifth class with a uniplanar node. Species XV. 1.

XVI. Cubic surface of the fourth class with four proper nodes. Species XVI. 1, 2, 3.

XVII. Cubic surface of the fourth class with two biplanar and one proper node. Species XVII. 1, 2, 3.

XVIII. Cubic surface of the fourth class with one biplanar and two proper nodes. Species XVIII.

XIX. Cubic surface of the fourth class with a biplanar and a proper node. Species XIX. 1.

XX. Cubic surface of the fourth class with a uniplanar node. Species XX. 1.

XXI. Cubic surface of the third class with three biplanar nodes. Species XXI. 1, 2.

XXII. Ruled surface of the third order and the third class. Species XXII. 1, 2, 3.

IV. "Experimental Investigations on the Stratified Appearance in Electrical Discharges."—"Effect obtained by varying the Resistance." By John P. Gassiot, F.R.S. Received December 11, 1862.

1. In the 'Proceedings of the Royal Society,' May 26, 1859, I have stated that, "on attaching the terminals of my water-battery (Phil. Trans. 1844, p. 39) to the wires of a carbonic acid vacuum-tube, inserted about 2 inches apart, I obtained a stratified discharge similar to that of an induction coil."

2. The battery remained as it was originally constructed, consisting of 3520 pairs of copper and zinc cylinders inserted in glass cells. As the rain-water with which each cell had been from time to time filled evaporated, they were again charged: this process of evaporation and recharging continuing for several years, during this lengthened period the battery was three or four times cleaned by dusting and wiping the cells, boards, and slips of glass on which the cells rested; but the constant deposition of dust and moisture had so far reduced the static effects of the battery, that this year it would scarcely elicit a spark of about $\frac{1}{5000}$th of an inch in air between the plates of my

micrometer electrometer (Phil. Trans. 1839), and I had therefore determined on taking the entire battery asunder, as well as in order to attach fresh zincs to the copper cylinders.

3. Previous to undertaking this somewhat tedious and troublesome process, it occurred to me to try what effect would be obtained from the discharge of the battery in carbonic acid vacua, by merely recharging it with brine in lieu of rain-water: the result of this experiment was such as to induce me for the present to forego my intention of having new zincs, particularly as a very large number of them were found to be much less oxidized than I had expected, and rather to turn my attention to some improved mode of insulation.

4. To accomplish this, the zincs were cleaned, and the old pieces of string with which they were kept from metallic contact with the copper cylinders were removed and replaced with new. The wood trays, on which the battery is placed, were cleaned, and carefully covered with a thick coating of shell-lac varnish, as were also the glass cells, the latter having been first heated in a sandbath in order to withdraw all trace of moisture before the varnish was applied.

5. On each tray slips of window-glass, also coated with shell-lac, were fixed *edge*ways, forming a kind of rail on which the cells were placed: the glass vessels being conical at the base, the strips of narrow glass presented little more than four points of shell-lac on which each cell rested. Those zincs which were found to be much oxidized were placed aside; and ultimately *three batteries* were completed, each of 1120 pairs of plates, forming, when connected with each other, *one* battery of 3360 cells: each cell was carefully charged with a saturated solution of common salt and water, and the trays, when placed on the racks, were separately insulated by resting on pieces of ebonite.

6. It will be observed that I have reduced my battery from 3520 to 3360 pairs of elements; the tension, as shown by the spark discharge, was nearly the same as when it was originally charged; but I have observed, after the battery has rested for a short time, the first discharge between the wire terminals in air appears to be more dense, presenting the same appearance as the discharge of a weakly-charged Leyden jar. The purport of this communication is not, however, to describe the general effects obtained by the

battery, many of which require more time for verification than I at present have at my disposal, but to lay before the Royal Society certain novel results which I have obtained, and which I hope may tend to elucidate, and possibly assist in explaining, the phenomena of what is termed the stratified electrical discharge.

7. I continue the practice I originally adopted of numbering my vacuum-tubes*: during the progress of my experiments, I found that the discharge of the battery was much more sensible to the slightest variation of the state of tension in each of these tubes, than that of the induction coil; the sudden disruption in the discharge of the latter presents greater obstacles to the more careful study of the phenomena than is offered by the direct discharge of the battery.

8. I soon ascertained that in some of my vacuum-tubes I was enabled to study the action of the discharges under peculiarly favourable conditions. I anticipate that these conditions may be still further improved; but, from the results I have already obtained, I venture the opinion that it may be doubtful whether the true theory of electricity as developed by the voltaic battery will be correctly explained, unless by carefully experimenting with batteries satisfactorily insulated. The battery I have described, with the improved method of obtaining vacua, first suggested to me by Dr. Frankland, offered me the opportunity of examining the discharge under conditions heretofore unknown.

9. The vacuum-tubes in which the experiments were made, and which relate to the subject of this communication, were Nos. 70, 248, 315, 319, 320, 324. These I shall refer to in the order of the experiments.

No. 248 (fig. 2 in woodcut) is about $2\frac{1}{2}$ inches long, 1 inch diameter: to the platinum wires small balls of coke are attached, about $1\frac{1}{2}$ inch apart, the wires being protected inside the vacuum, as far as the balls, by glass tubing.

No. 70 (described Phil. Trans. 1859, p. 151) is 14 inches long, with platinum wires 12 inches apart: a small glass bulb containing crystals of iodine was placed in this tube before it was charged with carbonic acid; and after the vacuum had been obtained,

* Phil. Trans. 1859, p. 137: the tubes were marked with consecutive numbers, a note being taken of each as it was finally sealed.

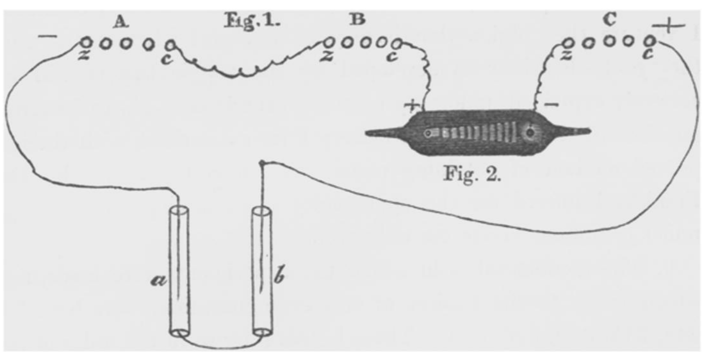
the glass bulb was broken. This tube consequently contains vapour of iodine.

No. 319 (Plate I.) is 20 inches long, 4 inches diameter: one terminal consists of aluminium, cup-shaped, about 3 inches diameter; the other a wire of the same metal. There is about 14½ inches between the cup and the wire.

No. 320 is 3 inches long, 1 inch diameter: very thin platinum wires, ⅝ths of an inch in length from the part protected by glass tube, are placed 1¼ inch apart from point to point in the tube.

No. 315 and No. 324 (Plates I. and II.) are about 5 inches long, with two balls of aluminium ⅜ths of an inch diameter, and 3 inches apart: the balls are attached to platinum wires, these wires being also, as in No. 248, hermetically sealed and protected with glass tubing.

The vacuum in each of the tubes was obtained by the carbonic acid process.



10. Fig. 1 represents the general arrangement of the apparatus: A, B, C, the three batteries (§ 5); *z* and *c* the zinc and copper terminals of each battery; the discharge of 1120 pairs, of 2240, or of 3360 can be thus separately examined. My general practice is to place the experimental tube between either one or the other of the batteries (fig. 2), the negative or zinc terminal of C being attached to one wire, and the copper or positive of B to the other. A and B are then connected, and the circuit is completed either by a resistance arrangement being attached to the zinc terminal of A and the copper terminal of C, or the circuit is closed by a wire. It was with the view of being enabled to vary the resistance at pleasure, that I

introduced the two tubes *a* and *b*, containing the distilled water, in the circuit. I ascertained that, by varying the depth to which the wires attached to the terminals of the battery are plunged in one or both of the tubes containing the water, the resistance could be regulated with great precision, and that it was immaterial in what part of the circuit the vacuum-tube or the resistance was introduced, provided the circuit is completed.

11. In proceeding to describe the experiments, I may premise that, in using the terms *intermittent* and *continuous* as applied to the discharge of the battery, I desire only to denote that when the discharge is examined by a vibrating or revolving mirror, in the *former* the appearance of a series of distinct discharges is plainly perceptible; in the *latter* this separation is not seen, but the discharge appears as a continuous light.

12. No. 248. In this tube, with 2240 series, luminous glows are observed on both balls, that on the negative being larger and more brilliant; in the dark discharge between the balls no trace of striæ can be seen; but at intervals a flash discharge takes place. The luminous glow on each ball appears as a continuous discharge; both glows at times flitter, attaching themselves sometimes on one, and then on the opposite sides of the balls; but even then they are not resolvable by the mirror.

13. When a resistance of about 3 inches in length, of distilled water placed in the glass tubes *a* or *b* (§ 10) (fig. 1), is introduced in the circuit, the discharge assumes the narrow stratified appearance which I described in a similar vacuum-tube*, fig. 2: the discharge is now intermittent, being separated by the revolving mirror: as the wire is depressed and the resistance thus reduced, the discharges when examined by the mirror are found to be quicker in succession, being less and less separated until we arrive at a point at which the discharge suddenly changes its character, appearing now as a continuous light. Gradually raising the wire, and thus increasing the resistance, the discharge becomes again stratified and intermittent, more or less as the resistance is increased or reduced.

14. No. 70. This tube contains vapour of iodine (§ 9): with the induction coil a luminous discharge is obtained, which exhibits very narrow striæ; with the battery of 3360 cells striæ are not observable,

* Proc. Roy. Soc. June 1860.

but luminous discharges are obtained, which are distinctly separated by the revolving mirror, and are consequently intermittent.

15. No. 319, with 2240 cells of the battery and a resistance introduced in the circuit: the discharge can, by careful manipulations, be modified so as to assume the appearance of a positive and negative discharge, impinging on and intermingling with each other without any dark space intervening (Plate I. fig. 3). Around the negative terminal the luminosity extends to the sides of the tube; from thence to the positive wire the discharge, as represented in the figures, takes place in a line of about 2 inches diameter, emitting a very faint light. The slightest variation in the resistance obtained by raising or depressing the connecting wire in the columns of distilled water (fig. 1) alters the appearance of the discharge to that represented in fig. 4, where the dark portion is clearly defined. As the resistance is reduced, the dark space increases by the positive discharge receding towards the wire, the negative becomes brighter and more clearly defined, at its termination an approach to stratifications is observed, until, as the resistance is further reduced, the discharge will suddenly assume the form (as in fig. 5) of two bright clouds,—the outer edges presenting a greenish-blue colour, crescent-shaped, clearly and sharply defined, of about $\frac{1}{8}$th of an inch diameter. The other portion of the clouds remains of a bright reddish purple, gradually deepening in colour in approaching the other edge, where it becomes less defined, leaving towards the next cloud a dark space. The same gradations of colour are observable in the inner cloud next the positive wire; but not so clearly or distinctly defined. The discharge is at this time continuous at intervals; but, without altering or apparently interfering with these striæ, sudden discharges take place: two or three similar cloud-like striæ will be observed at the positive wire; and at the same instant brilliant stratifications are visible, overlapping the negative (fig. 6)*.

With the 2240 series distinct sounds were heard in the tube; with the whole battery of 3360 series, the overlapping striæ would remain for several seconds, but the sounds were not appreciable until a magnet was presented near to, and in a line with, the overlapping striæ; the action of the magnet causes these striæ to spread along the surface of the glass tube, and in this state of the discharge the sounds were again audible.

* White tongue discharge (Phil. Trans. 1859, p. 140).

When sounds are heard, either with the lesser number of cells (2240) or when the overlapping striæ of the greater number are spread by the magnet, the discharge is resolved by the mirror, and as such is intermittent; but otherwise it is continuous.

Mr. Stewart, Director of Kew Observatory, was present when I made this experiment; he examined the separation of the discharge by the revolving mirror, and heard the sounds, under the conditions of the discharge which I have described.

16. No. 320. The discharge in this tube did not pass until the potash was heated, when a faint luminosity appeared, and immediately afterwards one, and then two, cloud-like striæ came from the positive wire, while round the negative a large brilliant glow was produced; as the discharge continued, the negative wire became red-hot. I have repeated this experiment many times with the same tube; platinum from the negative wire is deposited in a *lateral* direction, on the sides of the tube, as it would have been from the discharge of an induction coil.

17. No. 315 (Plates I. & II. fig. 7, &c.). With 3360 cells, the discharge in this tube is of a dazzling brilliancy, exhibiting 12 or 14 striæ (Dr. Faraday and Dr. Tyndall, who witnessed this experiment, counted 13); that nearest the negative ball, being truncated and of a pale-green colour, impinged on the luminous glow which surrounded that terminal (fig. 13).

With a resistance of the two columns of distilled water (fig. 1), each 18 inches in length, introduced in the circuit (§ 10), certain changes in the form and number of the striæ take place. Some of these I have endeavoured to represent by figs. 7, 8, 9, 10, 11, 19, and 13.

The wires attached to the terminals of the battery are placed inside the two tubes containing distilled water, connected with each other from the bottom; as soon as the wires touch the surface of the water, a faint luminous discharge is observed at each ball of the vacuum-tube. As one wire attached to the negative is slowly depressed, the two luminous discharges appear to travel towards or to attract each other; and at times I have noticed a portion of the positive luminosity to pass over and intermingle with the negative.

I tried the effect of a magnet on the discharge while in this state; but it was always extinguished *, and I could not obtain any satisfactory result.

* Proc. Roy. Soc. Jan. 1860.

Depressing the wire very gradually, the discharge assumes the form of fig. 7, the positive being sharply defined, the negative retaining much of its irregular termination, but each separated from the other by a dark interval of about one inch in length.

As the wire was further depressed in the water, the brilliancy of the positive and negative luminous glows increased; and when about 3 inches of one wire had been immersed in the water, a single clearly defined luminous disk burst forth from the positive, remaining steady and apparently fixed as in fig. 8.

As the wire was again further depressed, the luminous discharge at the positive slowly progressed along the tube until another bright disk appeared, remaining (as long as the wire was not further depressed) stationary as in fig. 9. At this time 13 inches of wire were in the water.

The resistance was again reduced by depressing the wire to 16 inches, when a third luminous disk was developed as in fig. 10; and at 18 inches depression, or the entire length of one column of water, a fourth disk was observed as in fig. 11.

In this state, while the four luminous disks were stationary, the wire attached to the positive terminal of the battery was depressed 4 inches; the luminous disks gradually closing on each other became more compressed, when a fifth was developed, fig. 12.

The luminous glow on the negative ball had gradually assumed a flattened surface towards the positive, appearing as a ring of light; depressing the wire to 7 inches in the water, the luminous disks closed but remained separate, and a 6th was observed; with 11 inches depression another, or the 7th, appeared, the negative glow increasing in brilliancy, retaining its flattened appearance. At this time, probably from the long-continued action, the power of the battery was reduced, and the 7th disk disappeared, retreating to and apparently absorbed by the luminosity on the positive ball; but on further depressing the wire, it was immediately reproduced; and on 15 inches insertion an 8th was obtained, the negative glow increasing in brilliancy, and the part nearest the positive presenting a still more flattened appearance.

Another clearly defined and separated disk of light was elicited, and then three or four came out in quick succession; the whole discharge now became unsteady and flittering, the luminous disks no longer remaining fixed or stationary.

18. From the first appearance of the luminous discharge in No. 315, until when thirteen or fourteen bright disks or separate striæ were observed, the discharge was not resolvable by a vibrating or a rotating mirror; with the full power of the battery, the disk nearest the negative was truncated and impinged on the glow which surrounds that ball (fig. 13): this truncated disk was also distinguishable by its pale green colour ; those in its nearest contiguity had more or less a reddish tinge ; the round negative glow was brilliant and of a bluish-white colour ; minute bright scintillations emanated from the negative ball, while distinct luminous flash discharges took place through the striæ. On examining these intermittent discharges by two revolving mirrors, kindly lent me by Professor Wheatstone, they appeared stratified ; but whether this did not arise from the passing of these discharges through the bright and dark portions of the continuous discharge, might have been considered doubtful, had I not in another tube observed a similar stratified discharge under more favourable circumstances. This tube, No. 324, is of the same form and dimensions as 315 ; on heating it with a spirit-lamp when it was in the circuit of the battery, the luminous discharge showed four clearly defined separated striæ, which remained fixed and steady in their relative positions ; in this state momentary stratified discharges were observed at intervals of from five to ten seconds, these striæ assuming a conical form, as in Plate II. fig. 14.

I have observed somewhat similar intermittent discharges with the nitric-acid battery, possibly under more favourable conditions ; and with a more extended series than I then used*, the true nature of this discharge may be ascertained.

19. The discharge from an electrical machine when passing through air in the dark, presents the well-known form of a brush at the end of the wire attached to the prime conductor, and of a star at the point of another wire attached to the rubber, or in connexion with the earth. I have shown† that if this discharge is allowed to pass through a vacuum-tube, stratifications will be obtained similar to those from an induction coil, and that the discharge of a Leyden jar, if passed through a wet string and a vacuum tube, is stratified‡ ; these

* Proc. Roy. Soc. March 1860.

† Phil. Trans. 1858, p. 6, sect. 21.

‡ Phil. Trans. 1858, p. 15, sect. 53.

discharges are consequently identical, and only differ in their appearance according to the media through which they are passed.

20. In a former communication to the Royal Society*, I have also shown that the stratified discharge can be obtained by a single disruption of the primary current of an inductive coil, however long may be the vacuum-tube through which the discharge is passed. If no addition is made to the battery with which the primary wire of the apparatus is connected, or no alteration is made in the arrangement of the coil, so as to increase or diminish the intensity of the discharge, the stratifications will always present the same appearance and form, occupying the same spaces and positions in the vacuum-tube; but if any change is made so as to alter the intensity, then a correspondiug alteration will appear in the discharge, *the striæ assuming a different shape, and the bright and dark divisions occupying different positions.*

21. When a galvanometer, a vacuum-tube, and a solution of iodide of potassium are arranged so as to form a continuous circuit with the secondary coil of an inductive coil, not only is a luminous stratified discharge produced, but the needle of the galvanometer will be deflected, and iodine will be evolved by the induced *momentary* action; we thus obtain in this discharge all the indications and conditions of a true voltaic circuit.

In the *continuous* discharge of the battery we have the same indications as that of the *momentary* current of the closed circuit of an induction coil, and neither is resolvable by the rotating mirror.

The stratified discharge from a *single* disruption of the primary wire of the induction coil, and the continuous discharge of the voltaic battery, are therefore identical in their character.

22. With these preliminary observations, I now propose to examine the results obtained from the discharge of an extended series of the voltaic battery in vacua described in this communication.

1st. No. 248. The discharge under certain conditions is continuous, and under other conditions it becomes intermittent. These conditions are, that without any resistance introduced in the circuit, except that inherent in the battery, the discharge cannot be resolved by the rotating mirror, and so far may be considered as continuous; but when a certain given and described resistance is introduced in the

* Phil. Trans. 1858, p. 9, sect. 30.

circuit, the discharge becomes intermittent; with an increased resistance the number of discharges in any given time is reduced, the duration of such intermittent discharges being distinctly resolvable by the rotation or vibration of the plane of a mirror in which they can be reflected.

2nd. No. 70. In this very imperfect vacuum, containing vapour of iodine, the battery does not elicit any striæ, but by the revolving mirror the discharge is found to be intermittent. With the induction coil the discharge in this tube elicits clearly defined but very narrow striæ; from the coil we have a discharge of high intensity which elicits stratifications, although they are not attainable by the lower intensity of the battery.

3rd. No. 319. We obtain evidence of two distinct states of a discharge, of colour in the striæ, and, under certain conditions, of sound.

4th. In No. 320 we have experimental proof that in the more perfect vacuum the discharge will not pass, confirming my former result obtained with the coil (Phil. Trans. 1859, p. 156), that the presence of a certain amount of matter is indispensable, and that during the discharge heat is developed.

5th. In No. 315, under all conditions of resistance described, the discharge of the battery is stratified, but cannot be resolved by the revolving mirror: in this tube we are enabled to determine and regulate the number of striæ, to some extent alter their colour, to fix and determine their position, separating or closing up the dark space between the luminous disks, these changes being entirely due to the amount of resistance introduced in the circuit.

The form, or figuration of the striæ, and the positions they occupy in the vacuum-tube, appear by these experiments to depend upon two separate and distinct conditions:—

1st. The power or energy of the battery.

2nd. The state of tension of the highly attenuated matter through which the discharge is visible.

The striæ can be controlled, their number increased or reduced, and their places or positions in the tubes altered by the introduction of measurable amount of resistance in the circuit; and thus they appear to indicate the amount of force of tension which exists in a *closed* circuit of the battery, as the divergence of the gold leaves of an

electroscope denotes the evidence of tension *before* the circuit is completed.

In my former communications to the Royal Society I have alluded to the direction of a force in the induction discharge from the positive towards the negative (Phil. Trans. 1858, p. 16, sections 57, 58).

In 1859 I observed that there was also a tendency or indication of a force emanating from the negative wire (Phil. Trans. 1859, pp. 140, 142, 153, sections 68, 72, 99); the actual disruption of the particles from the negative terminal also indicates a force; and this disruption is as freely obtained by the continuous discharge of the battery (§ 16) as it is by the intermittent discharge of the induction coil.

I have always observed that with the lowest state of intensity with which the discharge can be obtained from an induction coil, the striæ are wider apart and the dark space between the positive and the negative is much extended; under some conditions of the discharge it is the negative, and not the positive, that assumes the dominant character.

The form of the striæ in the battery discharge, as observed in No. 315, figs. 7, 8, and 9, presents an appearance somewhat analogous with the stationary undulations which exist in a column of air when isochronous progressive undulations meet each other from opposite directions, and on the surface of water by mechanical impulses similarly interfering with each other.

May not the dark bands be the nodes of undulations arising from similar impulses proceeding from positive and negative discharges?

Or can the luminous stratifications which we obtain in a closed circuit of the secondary coil of an induction apparatus, and in the circuit of the voltaic battery, be the representation of pulsations which pass along the wire of the former and through the battery of the latter, impulses possibly generated by the action of the discharge along the wires?